A FUZZY ARRAY-BASED CLUSTERING METHOD IN TEAM BUILDING

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Abstract: An array-based clustering approach is proposed as an effective mean for providing an alternative solution in team building problem. The proposed approach generates a systematic formation of task and team member families by sequencing the rows and the columns of a task-personnel incidence matrix. To obtain the task-personnel incidence matrix, a fuzzy sets approach will be proposed to combine two fundamental incidence matrices: the task-discipline and personnel-discipline incidence matrices. The proposed method is demonstrated by applying to an example in team building problem.

Keywords: Team building, Fuzzy sets, Array-based clustering algorithm, Task assignment

1. INTRODUCTION

Nowadays, companies need to effectively manage their product development projects in order to deliver their products to the market as early as possible and to maintain their competitive advantages. Generally, design projects require a multi-competency team involving members coming from different functional departments and possessing different competencies. Team building has become an increasingly challenging issue for the project leaders, especially when facing complex development situations.

1.1 Team building approach

Generally, there are two major procedures in team building: task organization and team member selection. The solving methods existing in literature can be various. (Chen, 2005) and (Chen and Lin, 2004) proposed an integrated methodological framework in team members assignment: (1) Project task model, (2) Team member model and (3) task-member assignment model. The objective of this research is to develop a framework for project task coordination and team organization from the concurrent engineering perspective in order to assign the right tasks to the right team members. (Braha, 2002) proposed a team-building approach based on task partitioning. Two main issues are addressed, (1) how to specify task dependencies, and (2) how to optimally partition the tasks among a number of teams. (Zakarian and Kusiak, 99) emphasized the importance of multifunctional teams in product development. The authors proposed a hierarchical architecture using in multifunction team building based on QFD and AHP method. The proposed architecture shows the relationship among team members, product characteristics and customer requirements. (De Korvin et al., 04) developed a personnel selection model for a multiple phase project. The fuzzy compatibility method has been used in order to select the potential team members for each project phase. However, this work did not specify competency attributes in project task characterization.

1.2 Task- and team member characterization

Numerous works about team building concern psychological and sociological aspects (personality types, teamwork, leadership, communication skills, decision-making ability etc.) (Fitzpatrick, 04), (Chen and Lin, 04), (Acuna and Juristo, 04). Technical competency is the most common attribute used in team building literature in order to characterize tasks and team members (Zarakian and Kusiak, 99), (Tseng et al., 04), (Hadj-Hamou and Caillaud, 04), (Fitzpatrick, 04), (Tsai *et al.*, 03). (De Korvin *et al.*, 04) emphasized that the important factor in selecting human resources to a team are the technical competencies. These competencies will be required to implement the various activities for each phase of the project. Technical competencies can be seen as competencies required by a task and competencies acquired by a person or a team.
Concerning competency characterization, some authors (F. Belkadi *et al.*) proposed two types of competency attributes: technical and cognitive knowledge. In our approach, we could focus on different types of competency attributes to characterize task and member. The proposed method in this paper is generic. For instance, attributes could

be either technical knowledge (such as: to know disciplines, to use tools, to apply methods, etc), or soft capacities (such as: organizational, decisional, relational, etc). It may depend on the industrial application. Generally, discipline is defined as "a branch of learning", for example: robotic, image treatment, acoustics, thermodynamics, etc.

1.3 Competency structuring and team building

The objective of competency structuring is to give a global image of competency to the project managers and to help them to deal with a multi-functional team building problem. In team building literature, team members belong to a functional department. But in the design of innovative products, new jobs (that is, new tasks) may appear; some persons may leave or be recruited by the company. So the departments may evolve. No existing method has been proposed to link task- and personnel evolution.

1.4 Dynamics of competency

Selecting team members is a multi-criteria problem solving. Many criteria have been considered in literature such as: budget consideration; workload; availability of technical/soft competency; dynamics of competency. (Boucher *et al.*, 2006) indicated that competencies can be seen as three distinct views: the static, functional and evolution views.

- The static view concerns identification, structuring and evaluation of competencies.
- The functional view concerns the mechanisms of competency mobilization in a working context where the goal is to make an efficient use of available competencies.
- The evolution view deals with the notion of dynamics of competency.

Dynamics of competency of an individual directly depends on the tasks that they have been assigned. Assigning a task to an individual can raise or at least maintain his/her acquired skills. In our knowledge, the dynamics of competency hasn't been treated yet in team-building literature.

The structure of this paper is composed of two parts: first we focus on competency structuring using a fuzzy array-based clustering method; second, we present how to build a team from a given mission requirement.

2. BACKGROUND: SOLUTION APPROACH

2.1 Fuzzy relation

Principle. Since fuzzy relations from X to Y are fuzzy sets on the Cartesian product XxY, for every $(x, y) \in X \times Y$, the quantity $R(x, y)$ is interpreted as the strength of the existing R-link between x and y.

Fuzzy-Set-Theoretic Operations on Fuzzy Relations

Starting from two fuzzy relations R_1, R_2, from X to Y, we may consider:

- the fuzzy union of R_1 *and* R_2, denoted $R_1 \cup R_2$
  $R_1 \cup R_2 : X \times Y \to [0,1]$
  $(x, y) \mapsto \max(R_1(x, y), R_2(x, y)), \forall (x, y) \in X \times Y$
- the fuzzy intersection of R_1 *and* R_2 ,denoted $R_1 \cap R_2$
  $R_1 \cap R_2 : X \times Y \to [0,1]$
  $(x, y) \mapsto \min(R_1(x, y), R_2(x, y)), \forall (x, y) \in X \times Y$

Composition of fuzzy relation. There are many different ways to define a composition of two suitable fuzzy relations. The most common one is the so-called sup-min composition as introduced by Zadeh (1971), (Klir and Floger, 1988), (Kerre, E.E., 1991). Let X, Y and Z be ordinary non empty sets, R_1 is a fuzzy relation from X to Y and R_2 is a fuzzy relation from Y to Z. The sup-min composition $R_1 \circ R_2$ is given as the following fuzzy relation from X to Z:

$$R_1 \circ R_2 : X \times Z \to [0,1]$$
$$(x, z) \mapsto \sup_{y \in Y} \min(R_1(x, y), R_2(y, z)), \forall (x, z) \in X \times Z,$$

If the involved universes are finite, i.e., X={$x_{1,\dots,}\ x_p$}, Y{ $y_{1,\dots,}\ y_q$}, Z={$x_{1,\dots,}\ x_r$}, with

$$R_1(x_k, y_l) = R^1_{kl},\ \ R_2(y_l, z_m) = R^2_{lm} \quad \text{then}$$
$$(R_1 \circ R_2)(x_k, z_m) = \max(\min(R^1_{k1}, R^2_{1m}), \min(R^1_{k2}, R^2_{2m}), \dots, \min(R^1_{kq}, R^2_{qm})).$$

(Kerre, E.E., 1991) emphasized that in some cases, another composition than the sup-min composition is more suitable.

2.2 Array-based clustering approach

An array-based clustering algorithm is one of the algorithms widely studied in the literature. One common characteristic of this algorithm is that all the methods consecutively reorder the rows and columns according to an index until the diagonal blocks are formed. An array-based clustering approach is one of group technology algorithm. Originally, this approach is applied in manufacturing cell formation in order to group similar part families on dedicated clusters of machines. Examples of array-based clustering algorithms are: ROC (Rank Order Clustering) (King J.R. 1980), ROC2 (King J.R. and Nakornchai V., 1986), DCA (Direct Cluster Algorithm) developed by Chan and Milner (1982), BEA (Bond-Energy Algorithm) developed by McCormick et al. (1972), (Mak K.L. *et al.*, 2000). The work of (Chu and Tsai, 1990) presented a procedure for evaluating alternative clustering algorithms under different measuring criteria.

3. PROPOSITION OF A TEAM BUILDING METHODOLOGY

In this paper, our proposed method is a first step to integrate task- and personnel evolutions in companies when doing team-building.

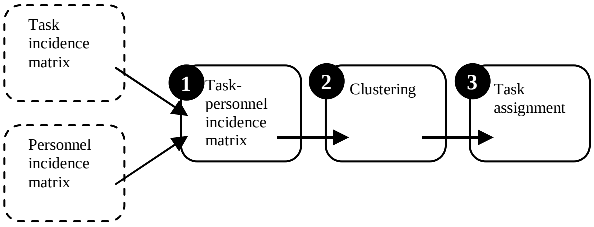

Fig. 1. Team building methodology

This approach will group similar persons on dedicated clusters of tasks and make task assignment easier to the project leader, because of the limited team member proposed in each family. The proposed methodology is split up into 3 major phases (Fig.1), as follows: generate a task-personnel incidence matrix; identify task-personnel families by clustering; assign tasks to team members. In this part, we describe these phases.

3.1 Generate a task-personnel incidence matrix

An incidence matrix is a matrix that shows the relationships between two classes of objects. If the first class is *X* and the second is *Y*, the matrix has one row for each element of *X* and one column for each element of *Y*. The fuzzy approach presented here is based on incidence matrices.

The first phase of the method consists of four different steps:

- Identify relevant attributes to characterize both task and personnel. It may be technical or soft competencies. In our example, we consider these attributes as being disciplines.
- Evaluate chosen attributes for a particular task (see in table.1: *Task-discipline incidence matrix*)
- Evaluate chosen attributes for a team member. (see in table.2: *Personnel-discipline incidence matrix*)
- Define a compatibility indicator between task and team member.
- Generate a task-personnel incidence matrix. (see in table.3: *Task-personnel incidence matrix*)

Fuzzy relation and Compatibility indicator. The similarity measure is one of the methods often used in team selection. This method finds the shortest distance between two skill sets, so as to find the appropriate candidate. Some distance measures have been mentioned in literature, for instance, Hamming distance (Canos, 04), (Boucher *et al.*, 2006). The disadvantage of existing measures is that they do not take into account the positive (or negative) measure as representing over-competency (or under-competency). Therefore, we propose a compatibility indicator as a distance measure that will be applied, instead of the sup-min composition normally used in fuzzy relation, in order to find the best correlation value between two fuzzy sets.

Let T, D and P denote ordinary non empty sets. Let R_1 be a fuzzy relation from T to D and let R_2 be a fuzzy relation from D to P. Then ($R_1 \circ R_2$) is a fuzzy relation from T to P. Let us denote

$T=\{t_{1,\ldots,}\ t_p\}$, $D=\{\ d_{1,\ldots,}\ d_q\}$, $P=\{p_{1,\ldots,}\ p_r\}$,

$R_1(t_k, d_l) = R^1_{kl}$, $\quad R_2(d_l, p_m) = R^2_{lm}$.

$(R_1 \circ R_2)(t_k, p_m)$ Compatibility indicator between the task *k* and the team member *m*

R^1_{kl} Required level of discipline *l* by a task *k*,

R^2_{lm} Acquired level of discipline *l* in the team member *m*.

The overcompetency $(R^1_{kl} < R^2_{lm})$ is a case indicating that the acquired discipline level of a person is higher than the task requirement. The undercompetency $(R^1_{kl} > R^2_{lm})$ is a case indicating the lower competency level of a person compared to task. In our approach, we consider only the undercompetency case and propose the following function to calculate a compatibility indicator.

$$(R_1 \circ R_2)(t_k, p_m) = 1 - \frac{\sum_{l=1}^{q} \max(0, R^1_{kl} - R^2_{lm})}{\sum_{l=1}^{q} R^1_{kl}} \qquad (1)$$

This composition method ($R_1 \circ R_2$) can be interpreted as the strength indicator of such a relational chain.

3.2 Identify task-personnel families by clustering.

ROC clustering algorithm will transform the task-personnel incidence matrix into task/personnel families. Algorithm principle:

Step 1: For each row of the task-personnel matrix, calculate the decimal weight.

Step 2: Sort rows of the matrix in decreasing order of the corresponding decimal weights.

Step 3: Repeat the preceding two steps, for each column.

Step 4: Repeat the preceding three steps until the position of each element in each row and column does not change.

A weight for each row i and column j is calculated as follows:

$$\text{Weight for row i : } \sum_{k=1}^{n} a_{ik}\, 2^{n-k} \qquad (2)$$

$$\text{Weight for column j: } \sum_{k=1}^{m} a_{kj}\, 2^{m-k} \qquad (3)$$

where n is the number of member and m is the number of task.

Group Density Index (GDI). This array-based clustering method is simple to apply to the task/personnel matrix. However, it requires visual inspection of the output to determine the composition of the diagonal block formation. We adopt here the Group Density Index proposed by (Tseng, *et al.* 2004). This index will be used to identify the potential groups after using the ROC algorithm. The variables n' and m' refer, respectively, to the number of rows and the number of columns, in potential groups. The following function will be used to calculate the GDI index.

$$GDI = \frac{\sum_{i=1}^{n'}\sum_{j=1}^{m'} a_{ij}}{m'n'} \qquad (4)$$

3.3 Assign tasks to team members.

The task assignment contains a group of tasks (mission requirement) to be accomplished. The mission requirement is defined here as a set of tasks $\{t_1 ... t_n\}$. For each task, the relative performance level will be defined in term of $\{e_1 ... e_n\}$.

4. AN ILLUSTRATIVE EXAMPLE

4.1 Problem formalization

Table 1 Task-Discipline incidence matrix (R_1)

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
T1	0,8	0	0,2	0	0,1	0,9	0	1	0	0
T2	0	1	0,7	1	0	0	0,6	0	0,3	0
T3	0	0	0	0	0,9	0	0	0	1	0
T4	1	0	0,1	0	0	0	0	0,7	0	0
T5	0	0,8	0	1	0	0	0,4	0	0	0
T6	0,2	0,3	0	0	0	1	0	0,8	0	0
T7	0	0	0,1	0,1	1	0	0	0	1	0,7

Table 2 Personnel - Discipline incidence matrix (R_2)

	P1	P2	P3	P4	P5	P6	P7
D1	0,7	0	1	1	0	0,2	0
D2	0	0,5	0	0,9	1	0	0,9
D3	0	0	0,3	0,2	0,4	0	0,6
D4	0,3	0	0	0,7	0,7	0	0,8
D5	0	0,7	0	0	0	0,9	0
D6	0,7	0	1	0	0	0	0
D7	0	0,9	0	0,5	0	0,6	0
D8	0,6	0	0,6	0,8	0,2	0	0,1
D9	0	0,5	0	0	0	0,7	0
D10	0	0,7	0	0,1	0	0,6	0
Salary/month (euros)	2,500	2,350	2,650	2,100	2,150	2,400	2,300

A design project with 7 tasks required 10 disciplines is used as an illustrative example. This design department has 7 members; each member knows a set of different disciplines and related performance levels. We may consider a set of tasks *t*, a set of disciplines *d* and a set of personnel *p*. where $R_1(t_k, d_l)$ = the degree to which task t_k requires discipline d_l to be carried out, and $R_2(d_l, p_m)$ =the degree to which discipline d_l is known by the person p_m. The task-discipline and personnel-discipline matrix are shown in tables 1 and 2.

4.2 Task-personnel incidence matrix

Integrating the fuzzy relation R_1 and R_2, we will obtain the table 3 ($R_1 \circ R_2$). The value of compatibility indicator $(R_1 \circ R_2)(t_k, p_m)$ can be obtained from the equation (1). The value in this table indicates the compatibility indicator that can be interpreted as the performance level of a person (*p)* to achieve a task (*t*).

4.3 ROC Algorithm and GDI index

The final matrix generated by the ROC algorithm is shown in table 4. Then, the GDI index (in equation 4) will be calculated to measure the group density of the possible solution. We obtained the GDI index for each potential group as follows: GDI1=0.773; GDI2=0.62; GDI3=0.723. The final decomposition obtained is shown as follows.
Group 1 : {T4,T1,T6} with {P3,P1}
Group 2 : {T2,T5} with { P4,P5,P7}
Group 3 : {T7,T3} with {P6,P2}.

Table 3 Task-personnel incidence matrix ($R_1 \circ R_2$)

	P1	P2	P3	P4	P5	P6	P7
T1	0,69	0	0,86	0,41	0,14	0,07	0,1
T2	0,08	0,39	0,08	0,5	0,58	0,25	0,64
T3	0	0,63	0	0	0	0,84	0
T4	0,72	0	0,94	0,72	0,17	0,11	0,11
T5	0,13	0,43	0	0,65	0,65	0,22	0,7
T6	0,65	0,13	0,78	0,3	0,22	0,09	0,17
T7	0,03	0,66	0,03	0,07	0,07	0,76	0,07

Table 4 Composition matrix with ROC algorithm (competency structuring)

		PC-1		PC-2			PC-3	
		P3	P1	P4	P5	P7	P6	P2
TC-1	T4	0,94	0,72	0,72	0,17	0,11	0,11	0
	T1	0,86	0,69	0,41	0,14	0,1	0,07	0
	T6	0,78	0,65	0,3	0,22	0,17	0,09	0,13
TC-2	T2	0,08	0,08	0,5	0,58	0,64	0,25	0,39
	T5	0	0,13	0,65	0,65	0,7	0,22	0,43
TC-3	T7	0,03	0,03	0,07	0,07	0,07	0,76	0,66
	T3	0	0	0	0	0	0,84	0,63
Salary/month (euros)		2,650	2,500	2,150	2,300	2,100	2,400	2,350

Result Interpretation. We consider here two possible cases: competency structuring and task assignment. Competency structuring considers all existing design tasks, while task assignment considers only a set of tasks in a specific design project. From the clustered result in table 4, we obtain the competency structuring in which three homogeneous blocks (departments) are formed in order to perform three groups of task. In the next section, the task assignment case will be studied and the result of competency structuring obtained in table 4 will be used in studying our task assignment case.

4.4 Task assignment

Problem formalization. Suppose we have to build a team to perform 5 tasks for a new product development. The mission requirement is composed of {T2, T5, T6, T4, T7}, see also in table 5. Each task has been identified the relative performance level (e_j). We assume here that each task is assigned for a single team member and this team member works full time for the task assigned.

Performance-based and cost-based solution. We consider here two possible solutions: performance-based and cost-based solution. The objective of performance-based solution is to maximize the global performance of a team as the objective of cost-based solution is to minimize the cost.

I. Evaluation procedure: performance-based solution

Step 1: Initialize the mission requirement with its relative performance levels, e_j.

Step 2: For each task, t_k, generate the possible qualified candidates, then present the compatibility indicator of the qualified member in a decreasing order.

Step 3: Select the candidate for each task

Step 4: Use cost criteria if there are candidates with the same performance level.

Step 5: Calculate the global performance

Numerical results In this section, we use the result obtained from table 4 to demonstrate how our task assignment method works. Each task group selects the qualified candidates from the correspondent team member group. For example, Task 2, first task in mission assignment, is in task group 2 (TC-2) so the qualified candidates have been selected from team member group 2 (PC-2). For task 2 with the given threshold of 0.7, the candidate P4, P5 and P7 are qualified. The candidate P7 has been assigned to this task (best compatibility). Then, we continue to the task 5. This task is in the same group as task 2. The candidates P4,P5,P7 have been qualified, but P7 has been assigned formerly, so the candidate P5 will be assigned. If there are candidates with the same compatibility level, we select the one who costs less to the project. The information about candidate's salary is shown in table 4.

Table 5 Team building (I)

Mission requirement	T2	T5	T6	T4	T7
Relative importance of each task (e_j)	0.5	0,2	0 ,15	0 ,1	0,05
Possible candidate	P4, P5, P7	P4, P5, P7	P3, P1	P3, P1	P6,P2
Solution based on Performance criteria $(R_1 \circ R_2)(t_k, p_m)$	P7 (0,64)	P5 (0,65)	P3 (0.78)	P1 (0.72)	P6 (0.76)

Table 6 Team building (II)

Mission requirement	T2	T5	T6	T4	T7
Relative importance of each task (e_j)	0.5	0,2	0 ,15	0 ,1	0,05
Possible candidate	P5,P7	P5,P7	P1,P3	P1,P3	P6,P2,P4
Solution based on cost criteria $(R_1 \circ R_2)(t_k, p_m)$	P5 (0.7)	P7 (0.64)	P1 (0.72)	P3 (0.94)	P6 (0.76)

Global performance of team:

$$g = \frac{\sum_j e_j * (R_1 \circ R_2)(t_k, p_m)}{\sum_j e_j} \quad (3)$$

g = (0.64*0.5)+(0.65*0.2)+(0.78*0.15)+(0.72*0.1)+(0.76*0.05)
= 0.67

II. Evaluation procedure: cost –based solution

Step 1: Initialize the mission requirement with its relative performance levels (table 6)

Step 2: For each task, t_k, generate the possible qualified candidates, then present the qualified members in an increasing order

Step 3: select the candidate with the lowest salary

Step 4: Calculate the global performance

Numerical results In this example, for task 2, the candidate 5 will be selected in stead of candidate 7 because the candidate 5 has lower salary. The global performance of team is calculated as follows:

g = (0.7*0.5)+(0.64*0.2)+(0.72*0.15)+(0.94*0.1)+(0.76*0.05)
= 0.718

In table 6, we note that P4 can be a good candidate (0.72) to task 4 with the lower salary compared to P3. However, P4 is not in the same group as task 4. So P3 will be allocated instead. To maintain the competency of the group, our solution will privilege P3 to be assigned to their own group first. This remark opens a perspective on competency dynamics modeling

5. CONCLUSION

This paper has presented a fuzzy relation and an array-based approach for team building and an illustrative example. This promising approach differs from the use of existing team building approach, because it has adopted a clustering algorithm to enable the tasks and the team members to be grouped into families (departments).

Our study in team member selection can be divided into two sections. At the beginning, we presented the method for competency structuring. The solution encourages the representation of attributes, characterizing a particular task or team member. The final solution has demonstrated the potential diagonal block (group) of tasks and team members. In the second part, we have studied the assignment of a given list of tasks, required by a project and included in the whole set of tasks. We have proposed an approach to build a multidisciplinary team corresponding to performance and cost criteria.

In this paper, some limitations should be noted, as they might lead to interesting perspectives in future research.

1) We have not considered the workload (man-hours) of team members and multi-projects task assignment.

2) In the context of competency dynamics and development, the performance level of team member

will gradually increase during the project execution and continuously decrease if they are not assigned to the task. The question that we might ask is: how can we apply this approach to support the global competency development of a company?

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